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PATENT SPECIFICATION

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DRAWINGS ATTACHED.

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COMPLETE SPECIFICATION.

Improvements in and relating to Electric Cables and Apparatus Incorporating Such Cables.

We, RANSBURG ELECTRO-COATING CORP., an Indiana corporation, United States of America, of 3939 West 56th Street, Indianapolis, Indiana, United States of America, do hereby declare the invention for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to electrostatic coating apparatus, in which particles of coating material are deposited upon the article to be coated with the aid of a high voltage electrostatic field. The invention also has relation to electric cables for use at high voltage in such apparatus.

In the past, electrostatic coating apparatus has taken a number of different forms but in general use is made of an electrode or electrode system which is maintained at a high potential with respect to the article being coated, which is advantageously at earth potential. In those forms of apparatus which have had the widest commercial use the electrode is directly associated with the atomising means, such as a head assembly, of which the electrode may form part.

In a typical installation the potential applied to this electrode may be of the order of several tens of kilovolts, for example at least 30 or 40 kilovolts, and may be as high as 100 kilovolts or more. The use of such very high voltages on an electrode which must be at least to some extent exposed calls for particular consideration.

Disruptive discharges from the electrode are generally undesirable for obvious reasons, but in the case where the coating material is a paint or the like which contains the volatile and inflammable components, there may be a more positive

danger of ignition or explosion of the vapour of the solvent in use. Apparatus of this kind also exists for use in the hand of an operator, or in conditions where it is possible for personnel to approach the electrode closely. In these cases there is the obvious danger of unpleasant shock, injury or worse to any person who may approach too closely.

In our prior specification No. 865,765, there is disclosed a spray-coating apparatus in which means are incorporated to reduce or eliminate these dangers, as may be required, such means comprising the use of a high value of resistance included in the electrical connection to the charged electrode.

As is pointed out in detail in that specification, the use of such resistance in conjunction with an electrode system that presents a low effective capacity will result in an improvement of the safety factor of the apparatus as regards fire or shock, and with appropriate values the apparatus can be made safe in either or both of these respects. In the specification referred to, there is included a description of an electrostatically operated spray gun, which, though making use of an electrode which in use is maintained at high potential, can be held safely in the hand, the voltage on the electrode decreasing rapidly on the approach of any earthed article, or any part of the person of the operator.

To secure this complete degree of safety it is essential that the effective electric capacity of the electrode and of any parts through which it is electrically connected should be kept to a low value. In this connection it is important to point out that the effective capacity of an electrode system is not the same as the conventional

[P. 1.]

5 tained at high potential, instead of embody-
 ing the customary highly conductive metal
 wire or the like for the transmission of the
 high voltage, employs a semiconductive
 10 element having a substantial distributed
 resistance. This element may conveniently
 consist of one or more layers of semi-
 conductive polyethylene or the like pre-
 15 ferably surrounding a flexible but re-
 latively inextensible core and in turn
 surrounded by a layer of flexible insulating
 material. Desirably, the latter layer is
 surrounded by an earthed braided wire
 sheath, which may be covered by an
 abrasion-resistant, easily cleanable coating.

Other features and advantages of the in-
 vention will appear from the following
 description of embodiments thereof, given
 by way of example, in conjunction with
 20 the accompanying drawings, in which:—

Figure 1 is a somewhat diagrammatic
 view showing an electrostatic spray-coating
 apparatus employing a hand-held spray
 gun, and

25 Figure 2 is an elevation showing a pre-
 ferred form of high-voltage cable with its
 various layers broken away.

The apparatus shown in Figure 1 com-
 30 prises a spray gun, designated in its en-
 tirety by the reference numeral 10, a source
 11 of paint or other coating material, and
 a power pack or high-voltage source 12.
 The particular spray gun shown in Figure
 1 as an example of an electrostatic spray-
 35 ing device is of a type more fully illustrated
 and described in the aforesaid patent No.
 865,765. It comprises an elongated body
 15 of insulating material carrying at its
 rear end a handle member 16 having a
 40 conductive grip portion or handle 17 and
 at its front end a rotatable, electrically
 charged atomising head 18. Paint to be
 supplied to the interior of the head 18 is
 45 conveyed to the gun through a flexible
 hose 20, while power for rotating the head
 is transmitted through a cable 21. High
 voltage for charging the head is conducted
 to the gun through a flexible cable 22 and
 50 is applied to the head through a resistor 23
 housed within the body 15 and electrically
 connected at its front end to the head by
 means of a brush 24. It is to be under-
 stood that this invention is not limited to
 any particular form of electrostatic spray-
 55 ing device and that the one illustrated is
 shown merely by way of example. It is
 particularly noted that the invention is not
 limited to a hand gun, or to a device in
 which a single element, in this case the
 60 rotating head 18, serves as both a spray-
 forming means and an electrode.

A preferred form for the high voltage
 cable, shown in detail in Figure 2, com-
 65 prises a flexible, non-conductive central
 core 26 surrounded successively by a semi-

conducting layer 27, an insulating layer 28,
 a braided metal sheath 29, and an abrasion-
 resistant, easily cleanable, outer covering 30.
 As such cable is used in the apparatus of
 Figure 1, the metal sheath 29 is secured at
 70 its opposite ends to the gun and power
 pack, is electrically earthed, usually at the
 power pack, and electrically connected to
 the conductive handle 17 to earth it as
 well as the operator grasping it. The semi-
 75 conducting cable-layer 27 is electrically
 connected to the high potential or un-
 earthed terminal of the power pack and to
 the rear end of the resistor 23.

The semiconducting cable-layer 27 may
 80 be formed of polyethylene or some other
 similar flexible material incorporating car-
 bon black or other finely comminuted
 material in proportion such as will give the
 layer the desired resistivity. The resistance
 85 of the layer 27 per foot of length will de-
 pend upon its cross-sectional area and its
 volume resistivity, and those factors are co-
 ordinated so that the resultant cable has
 an average resistance of not less than one
 90 and preferably in the range one to five
 megohms per foot. Of course, higher
 values of cable resistance can be tolerated,
 but if the resistances are appreciably
 95 higher, and if unusually long cables are
 used, compensating adjustments may be re-
 quired in other circuit parameters. Since
 for a given operating voltage the insulating
 layer 28 must have a certain minimum
 100 thickness (about 3/16 of an inch has actu-
 ally been used in cables for this type of
 equipment) in order to sustain the poten-
 tial difference between the conductive layer
 27 and the earthed sheath 29, the diameter
 of the conductive layer will limit the
 105 minimum diameter of the cable as a whole.
 For reasons of economy, and also to avoid
 undesirable rigidity in the cable, it is
 therefore desirable that the conductive
 layer 27 have a relatively small diameter.
 110 On the other hand its radial dimension de-
 termines the nature of the electrical
 gradient which exists across the layer 28
 when the layer 27 is raised to high voltage.
 The larger the layer 27 the smaller will be
 115 the potential gradient at its surface; and if
 the layer 27 is too small, the potential
 gradient at its surface may be undesirably
 large. Taking all these factors into
 account, a layer 27 having a diameter of
 120 about one-eighth inch is appropriate for
 use with high voltage sources having an
 output in the neighbourhood of 50 to 100
 kilovolts.

The purpose of the central core 26 is to
 125 prevent or limit stretching of the conductive
 layer during the course of cable-manu-
 facture. Stretching of that layer would de-
 crease its diameter and also effect the
 volume resistivity of the material such as
 130

electrical capacitance of the system, but is that value of true capacitance which would make instantaneously available to support an electric discharge the same amount of energy as that in fact available from the cable. In stating that an element, such as the charging electrode or electrode system, or its equivalent, has a low effective capacity we mean that the element presents at a particular point such low true capacitance or such combination of true capacitance and electrical resistance that where the element is used in a high voltage apparatus of the character concerned, the energy contributed to disruptive discharge between such element and an opposed blunt electrode by the electricity stored in the system including the element is insufficient to render such discharge objectionable.

In a construction of a hand-held atomiser or spray gun, described in specification 865,765, an electrode of low effective capacity is arranged at the forward end of the elongated body of the atomiser. A high value resistor is connected at its forward end to the closely adjacent electrode and the rearward end of the resistor is connected to the high voltage supply through the central metal conductor of a flexible cable having an earthed conductive sheath. If the resistor has a resistance which is adequately high with respect to the applied voltage, and the effective capacity of the electrode is low, the increase in current which accompanies approach of the electrode to an earthed object will increase the voltage drop across the resistor at such a rate that the intensity of any sustained discharge that may occur from the electrode will be so low that it involves no objectionable shock or fire hazard.

While such apparatus may be made free from danger in respect to discharges that can occur from the electrode, it possesses a possible hazard in the flexible cable through which high voltage is applied to the resistor in the gun-body. In the use of such apparatus, the cable, which may have a length of many feet, commonly lies on the floor. In that position, the cable is subject to injury which might expose its central conductor or reduce the dielectric strength of its insulation. Such an accident could result in the occurrence of a high-intensity spark discharge between the central conductor and the earthed cable-sheath or any other earthed object; and in an atmosphere containing flammable vapours of the commonly used paint solvents such a spark could cause a fire. Although some resistance is sometimes incorporated in the high voltage supply, it is not possible to thereby eliminate, or reduce to a satisfactory extent, the hazard of a

spark resulting from cable-rupture. While a resistance in the voltage supply can limit the intensity of a steady-state discharge, it cannot control the discharge of electrical energy stored in the cable beyond the resistance.

The present invention concerns a high-voltage cable for supplying the electrode of an electrostatic spray-painting apparatus maintained at high voltage, which reduces the hazard attendant upon cable-rupture. A cable in accordance with, or for use in a system in accordance with the invention can be given adequate flexibility and can be light in weight.

In one aspect, the present invention consists of electrostatic spray coating apparatus wherein an electrode which in operation is required to be maintained at a high voltage is electrically connected to the insulated conductor of a high voltage electric cable for connection to a source of said high voltage, said conductor having a uniformly distributed resistance of not less than one megohm per foot length of the cable.

The cable used in apparatus according to the invention is advantageously provided with an outer flexible conductive sheath, which may in turn be overlaid by a further and outer layer of insulating material. In this case the design of the cable is preferably such that it has a low effective capacity. The expression "low effective capacity" used in this specification and the accompanying claims is to be understood as meaning such a combination of true capacitance and resistance that the energy contributed to a disruptive discharge between the cable high-voltage conductor and earth will be insufficient to ignite a mixture of air and flammable vapour or to deliver an unacceptable electric shock to a normal operator.

The invention also comprises electrostatic spray-coating apparatus including an electrode connected to a source of high voltage by way of an electric circuit including the insulated conductor of an electric high-voltage cable, said conductor having a uniformly distributed resistance which is not less than one megohm per foot length of the cable. Specifically, this aspect of the invention contemplates an electrostatic spray coating apparatus wherein a spray charging electrode is connected with the output electrode of a high voltage source by way of an electric circuit wherein the major portion of the circuit resistance is represented by the resistance of said cable conductor.

In one construction in accordance with the invention the flexible cable through which the spray-charging electrode of an electrostatic spray-coating device is main-

to increase its resistance. The cross-sectional area of the conductive layer and the nature of the material forming the layer are such that, unless its stretching is controlled during its formation and the application to it of the insulating layer 28, the resistance of the layer per unit of length could vary to an undesirable extent. While there are other ways of controlling such stretching, the most convenient way is to form it as a coating on a core 26 of more or less relatively inextensible material. Coarse threads of natural or synthetic organic fibres, glass roving, and glass strand are suitable materials for the core 26. Of course, this core is not an essential portion of the invention.

The insulating layer 28 must possess adequate insulating properties as well as adequate flexibility. Polyethylene is a suitable material for that layer.

The function of the outer cable-layer or covering 30 is, as previously indicated, to protect the braided metal sheath 29 from abrasion and also to facilitate cleaning the cable. Suitable materials for that covering are the natural and synthetic rubbers, polyethylene and the like. However, such materials are normally good electrical insulators; and it is desirable that the covering 30 possess a measure of conductivity in order to prevent its acquisition of a surface charge as a result of impingement on it of atmospheric ions inevitably present in the vicinity of electrostatic coating apparatus. Suitable conductivity can be imparted to the covering 30 by incorporating an adequate proportion of carbon black or graphite in the material from which it is formed.

In the circuit between the high-voltage terminal of the power pack and an electrode of an electrostatic spray gun, the portion of the total resistance provided by the cable described will vary with circumstances. One successful system embodying a power pack of 60 kilovolts output and a hand-held spray gun provided with a spray-charging electrode employs a 160 megohm resistor mounted in the gun and connected to the power pack through a conventional metallic conductor. By replacing the conventional cable of that system with a cable according to this invention having a length of 32 feet and a distributed resistance of five megohms per foot, it is possible to eliminate the necessity for any additional resistor in the gun. Where it is impractical to employ a cable providing all the resistance directly connected to the electrode, the cable may, and desirably will, provide a major portion of such resistance; but although the cable-resistance may provide only a portion, even a minor portion, of the total resistance, it still has

the advantage of making it possible to attain the desired degree of safety with a smaller resistor in the gun.

From the foregoing it will be apparent that in the event of the cable being ruptured or the high voltage conductor exposed in use, the danger of disruptive discharge will depend upon the effective capacity at that point. In the case of a conventional cable having a low resistance high voltage conductor it will be clear, as pointed out above, that the electrical capacity of the power pack and other circuit means directly connected to the conductor will contribute to the effective capacity at the point of exposure or rupture. By including resistance in the serial connection afforded by the cable, the effect of such associated capacity is largely reduced or eliminated. There remains the capacity of the cable itself, and for the complete elimination of the danger of shock or fire the cable itself must present at any point along its length a low effective capacity. A safe effective capacity is definable as one in which the energy contributable to a disruptive discharge between the point of rupture or exposure of the high voltage conductor does not exceed that of a metallic sphere of three centimetres radius, at the same point and preferably does not exceed that of a sphere of one centimetre radius.

It follows that the cable in accordance with the present invention should have such combination of true capacitance and resistance as to have a low effective capacity at any point along its length.

Cables in accordance with this invention have been tested by rupturing the cable at various distances from the power pack. An explosion chamber containing an air-hexane mixture at 3°F. and atmospheric pressure was employed. A cable having a distributed resistance of 3.9 megohms per foot was connected with a power pack developing 100 KV output, with 130 megohms resistance in the pack in series between the high voltage point and the cable. Beginning with a 27 foot cable, the cable was cut shorter and shorter down to a 5 foot length without causing a discharge sufficient to ignite the hexane-air mixture.

In another example, a cable having a distributed resistance of 11.1 megohms per foot was connected to a power pack developing 150 KV with 480 megohms resistance in the pack between the high voltage point and the cable (pack resistance). Even when reduced to a length of only six feet, there was insufficient discharge to ignite the hexane-air mixture. The absence of a discharge capable of igniting the hexane-air mixture is indicative of the fact

that the effective capacity of the cable was less than that of a 1 cm. sphere.

In our prior specification No. 865,765, and as mentioned briefly above, the use of high resistance in the connection to the high voltage electrode of an electrostatic coating apparatus has an advantage that it secures a drop in the average potential gradient automatically, on the approach to the electrode of the article to be coated, or any other object at or near earth potential, or the potential of the other terminal of the high voltage supply. In our prior specification no. 865,766, it is pointed out that there is an optimum potential gradient for optimum atomisation with certain types of atomiser. The cable of the present invention can thus be used with advantage in a system in which safety from freedom or shock, considered at the electrode only, is not a primary requirement.

Another advantage of the cable 22 with its distributed resistance, as compared to the conventional cable with its metallic high-voltage conductor, is that the maximum voltage existing in the gun as a whole is reduced by the substantial voltage drop along the cable between the power pack and the gun. This simplifies the problem of providing, at the rear end of the gun, insulation or air-gap lengths adequate to take care of the potential difference between charged gun parts and the earthed handle.

In addition to the advantages just noted, a system employing the cable 22 is seen to have a further advantage when one considers the possible consequences of cable-rupture. In an electrostatic painting installation, the atomiser or atomisers are commonly located a substantial distance, for example fifteen or twenty feet or even more, from the power pack and the high voltage cable lies on the floor, where it is subject to injury as from falling objects or the passing of factory trucks over it. Should the insulating layer 28 be ruptured as the result of such an accident or from other causes, the exposure of the high-voltage conductor could result in an electrical discharge from the central conductor to the earthed metal sheath. If the central conductor were of metal, the energy stores in the capacity of the remaining cable length at full power-pack voltage would be available to create an initial discharge which would therefore be relatively intense. In an atmosphere containing the flammable solvent vapours of commonly used paints, such an intense discharge could easily cause a fire. However, with a cable in accordance with this invention embodying a central conductive element having a high value distributed resistance,

the capacity of the remaining cable section would be isolated from the point of discharge by this distributed resistance and the value of the initial as well as the steady state current would thus be limited by it. After the occurrence of the initial capacity discharge of low value the voltage drop between the power supply and the site of the rupture would be more than with a cable with a metallic core and thus the intensity of the steady state discharge would be materially limited and thereby reduce the fire hazard. In this connection, it may be noted that in an electrostatic spray-painting operation the greatest concentration of solvent vapours exists adjacent the atomiser, and if a cable-rupture occurred in that region practically the full resistance of the cable would be available to reduce the intensity of the electrical discharge. If the rupture occurred farther from the gun, less of the total cable resistance would be available and the discharge would be more intense; but, so far as likelihood of a fire is concerned, the increase in the intensity of the discharge would at least in part be offset by the lower concentration of solvent vapours at the point of rupture.

WHAT WE CLAIM IS:—

1. Electrostatic spray-coating apparatus wherein an electrode which in operation is required to be maintained at a high voltage is electrically connected to the insulated conductor of a high-voltage electric cable for connection to a source of high voltage, said conductor having a uniformly distributed resistance of not less than one megohm per foot length of the cable.
2. Electrostatic spray coating apparatus wherein an electrode is connected to a high-voltage source by way of an electric circuit including the insulated conductor of a high-voltage cable, said conductor having a uniformly distributed resistance of not less than one megohm per foot length of the cable.
3. Apparatus in accordance with claim 1 or claim 2 wherein said conductor has a uniformly distributed resistance of five megohms per foot length of the cable.
4. Apparatus in accordance with claim 1, claim 2 or claim 3 wherein said conductor is of a semiconductive material.
5. Apparatus in accordance with any of the preceding claims wherein said conductor has a core of non-conductive substantially inextensible material.
6. Apparatus in accordance with any of the preceding claims wherein said cable comprises an outer flexible conductive sheath.
7. Apparatus in accordance with claim 6 wherein said cable comprises a further

and outer layer of insulating material overlying said sheath.

8. Apparatus in accordance with claim 6 or claim 7 wherein said cable has a low effective capacity as hereinbefore defined such that any discharge of electricity therefrom which could present a fire hazard is avoided.

9. Apparatus in accordance with claim 6, claim 7 or claim 8, wherein said conductive cable sheath is earthed.

10. Apparatus in accordance with claim 2 wherein said circuit has a resistance of

at least one megohm per kilovolt of the potential of said high-voltage source, said cable conductor presenting the major portion of said circuit resistance. 15

11. Electrostatic spray coating apparatus substantially as hereinbefore described with reference to the accompanying drawings. 20

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